



Tackling U.S. energy challenges and opportunities: preliminary policy recommendations for enhancing energy innovation in the United States

Citation

Anadon, Laura Diaz, Kelly Sims Gallagher, Matthew Bunn, and Charles Jones. 2009. "Tackling U.S. Energy Challenges and Opportunities: Preliminary Policy Recommendations for Enhancing Energy Innovation in The United States." Cambridge: Report for Energy Technology Innovation Policy research group, Belfer Center for Science and International Affairs, Harvard Kennedy School.

Published Version

10.2172/948079

Permanent link

<http://nrs.harvard.edu/urn-3:HUL.InstRepos:29913519>

Terms of Use

This article was downloaded from Harvard University's DASH repository, and is made available under the terms and conditions applicable to Other Posted Material, as set forth at <http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA>

Share Your Story

The Harvard community has made this article openly available.
Please share how this access benefits you. [Submit a story](#).

[Accessibility](#)

ENERGY TECHNOLOGY INNOVATION POLICY GROUP

TACKLING U.S. ENERGY CHALLENGES AND OPPORTUNITIES

**PRELIMINARY POLICY RECOMMENDATIONS
FOR ENHANCING ENERGY INNOVATION
IN THE UNITED STATES**

**LAURA DIAZ ANADON, KELLY SIMS GALLAGHER,
MATTHEW BUNN, AND CHARLES JONES**

February 2009



BELFER CENTER

for Science and International Affairs

Harvard Kennedy School

DISCLAIMER

These recommendations are an intermediate product of the Energy Research, Development, Demonstration, & Deployment (ERD3) Policy Project of the Energy Technology Innovation Policy (ETIP) research group at the Belfer Center for Science and International Affairs of the Harvard Kennedy School of Government. This project has built on the expertise that the ETIP research group has built since its creation in 1997. For more details about ETIP please go to: www.energytechnologypolicy.org.

Although the full results from the analysis of the ERD3 project will not be ready until mid-2010, we would like to share some of our views about what will be needed to strengthen the U.S. energy-technology-innovation capabilities and accelerate the deployment of advanced technologies.

ACKNOWLEDGMENTS

The ERD3 Policy Project would like to thank the Doris Duke Charitable Foundation for supporting the project.

The Energy Technology Innovation Policy group would like to thank the William and Flora Hewlett Foundation, Packard Foundation, BP Carbon Mitigation Initiative, BP Alternative Energy, Shell Oil, and the Energy Foundation for their support of related research which has informed this project.

We would also like to thank our Advisory Board members, Henry Lee, and Jeff Bielicki for their advice and comments, Susan Lynch and Patricia McLaughlin for their help with editing, and Neal Doyle for his work with the layout. The opinions in this paper are those of the authors alone and do not necessarily reflect those of the funding sponsors or Advisors.

CITATION INFORMATION

© 2009 President and Fellows of Harvard College; Printed in the United States of America

The authors of this report invite liberal use of the information provided in it for educational purposes, requiring only that the reproduced material clearly state: "Reproduced from Laura Diaz Anadon, Kelly Sims Gallagher, Matthew Bunn, and Charles Jones, Tackling U.S. Energy Challenges and Opportunities: Preliminary Policy Recommendations for Enhancing Energy Innovation in the United States, (Cambridge, Mass: Energy Research, Development, Demonstration & Deployment Policy Project, Energy Technology Innovation Policy Group, Harvard University, February 2009)."

Cover Image: Turbines spin at the New Mexico Wind Energy Center, located 170 miles southeast of Albuquerque and 20 miles northeast of Fort Sumner.

Source: Sandia National Laboratories

TACKLING U.S. ENERGY CHALLENGES AND OPPORTUNITIES

PRELIMINARY POLICY RECOMMENDATIONS FOR

ENHANCING ENERGY INNOVATION IN THE UNITED STATES

EXECUTIVE SUMMARY

The incoming Obama Administration and the 111th Congress face enormous challenges and opportunities in tackling the pressing security, economic, and environmental problems posed by the energy sector in the United States and worldwide. Improving the technologies of energy supply and end-use is a prerequisite for surmounting these challenges in a timely and cost-effective way.

Accelerating the development and deployment of advanced energy-supply and end-use technologies will require a comprehensive strategy integrating efforts from invention to deployment, including strong leadership, alignment of policy incentives, consistency of policies, and a long-term view. In the following sections we outline our preliminary recommendations for near-term actions to strengthen the U.S. effort to develop and deploy advanced energy technologies. Our analysis is continuing, and we will be publishing long-term policy recommendations later this year. The budget recommendations in this paper are only for fiscal year (FY) 2010. They represent minimum levels based on ramping up from FY 2008 levels where such increases are most needed. They do not take into account the amounts provided in the recently approved economic recovery package.

Increase the Department of Energy (DOE) budget for energy research, development, and demonstration to \$6,060 million in FY2010 (from \$4,173 million in FY 2008), distributed as follows:

<u><i>Basic Energy Sciences</i></u>	<u><i>\$1,500 million</i></u>
-------------------------------------	-------------------------------

Progress in basic energy sciences is essential to developing new energy technologies. The Office of Science has engaged in planning and developed new initiatives which support the call for \$1.5 billion in FY 2010 found in the FY 2009 budget request.

<u><i>Fossil Energy</i></u>	<u><i>\$1,700 million</i></u>
-----------------------------	-------------------------------

Carbon capture and storage (CCS) has been identified by most analysts as an essential component of any comprehensive plan to reduce carbon dioxide emissions worldwide. This level of funding is required to begin a series of commercial-scale CCS demonstrations in various conditions.

<u><i>Electric Transmission and Distribution</i></u>	<u><i>\$220 million</i></u>
--	-----------------------------

Smart grid technologies are needed to ensure reliable and efficient electricity delivery. There should be both a smart grid R&D program and regional demonstration projects.

<u><i>Energy Efficiency</i></u>	<u><i>\$770 million</i></u>
---------------------------------	-----------------------------

Significant opportunities to improve energy performance exist in both vehicle technologies and building technologies, and energy storage.

<u><i>Renewable Energy</i></u>	<u><i>\$850 million</i></u>
--------------------------------	-----------------------------

Opportunities in the portfolio of renewable energy technologies – wind, geothermal, solar, and biomass – justify a substantial investment increase over FY 2008 levels.

<u><i>Hydrogen</i></u>	<u><i>\$220 million</i></u>
------------------------	-----------------------------

There are more opportunities in fuel cell technology than are being explored, justifying a modest increase in the hydrogen programs.

Nuclear Fission

\$350 million

Nuclear fission RD&D should focus on improving the factors that have limited nuclear power's potential as an energy option—cost, safety, security, proliferation-resistance, and waste management. Funding for the Global Nuclear Energy Partnership should be redirected to a portfolio of long-range R&D on improving both open and closed fuel cycles, and support for reactor designs the private sector can carry forward itself should be reduced.

Nuclear Fusion

\$450 million

Fusion is a long term prospect that also advances basic science. The U.S. must meet its commitments to ITER and maintain other fusion work.

Develop, publish, and implement a comprehensive U.S. energy innovation strategy

The United States urgently needs a comprehensive energy innovation strategy that integrates the full range of policy tools throughout the innovation chain from basic research through widespread diffusion in order to maximize the efficiency and outputs of the U.S. energy innovation system. The new White House Coordinator for Energy and Climate Change, the Office of Science and Technology Policy, DOE, and other public and private stakeholders should work together to develop, publish, and implement such a comprehensive approach. An integrated approach to energy innovation may well be more important than RD&D funding levels assigned to particular technologies.

Strengthen DOE's capacity to manage an expanded, integrated federal energy RD&D enterprise

Opportunities exist for improved effectiveness of effort. DOE should pursue a portfolio approach with a broad set of technologies at every stage of technological development. The Obama administration should establish expanded information-sharing between different energy-innovation efforts, more effective coordination of programs with the private sector, and full integration with the national strategy for energy technology innovation. Management changes should create greater communication and coherence rather than new layers of bureaucracy.

Create mechanisms for managing both demonstration projects and high-risk, high potential R&D

Both of these classes of innovation call for funding and management structures that do not exist within DOE today. Innovation at the pilot through commercialization stages requires procurement, funding, and decision rules more like that of private enterprise, to generate quality information about commercialized technology. In contrast, realizing opportunities for transformational technology requires stable, long-term funding, tolerance for risk, and the ability to learn from failure. Options include concepts such as a government-owned corporation to manage energy technology demonstration projects in cooperation with private firms, and an Advanced Research Projects Agency—Energy (ARPA-E).

Encourage expanded private-sector investment in energy innovation

Entrepreneurs will react to new rules and laws by innovating. Setting a price on carbon will provoke development of innovative ways to reduce carbon emissions. Government must also elicit private-sector innovation through creating and managing effective public-private partnerships. The federal government should increase its support to private RD&D by making permanent and expanding the research and experimentation tax credit, and by providing tax credits for U.S. companies building clean-energy demonstration projects at home and abroad.

Strengthen international cooperation in energy research

The United States should expand international cooperation in energy technologies, to reduce the costs and risks of energy innovation, increase the pace of cost reductions through expanded learning and deployment, and encourage other countries to deploy the technologies developed. At

the same time, the Obama administration should put in place mechanisms to manage the coordination and intellectual property issues raised by such efforts.

Target and better coordinate incentives for large-scale deployment of energy technologies

Policies aimed at accelerating deployment of energy technologies are often decoupled from key energy policy goals and poorly linked with policies for research, development, and demonstration. The Obama administration should encourage deployment by setting a price on carbon and strengthening targeted incentives in particular sectors – and should integrate these incentives as one key element of the comprehensive energy innovation strategy recommended above.

The energy challenges facing the United States and the world are daunting. But with a comprehensive strategy for and investment in energy innovation, new approaches to managing the effort, and policies for moving new technology into the market, the United States can meet these challenges and seize the opportunity for leadership in the markets for energy technology.

TABLE OF CONTENTS

Disclaimeri

Acknowledgementsi

Citation Informationi

Executive Summary ii

1 Introduction 1

2 Recommendations For DOE’s RD&D Budget.....2

2.1 The Context: Key Players in Energy RD&D2

2.2 Recommendations For DOE’s Basic Energy Sciences and ERD&D Budgets for FY 20104

2.3 Basic Energy Sciences4

2.4 Fossil Energy6

2.5 Electricity Transmission and Distribution.....7

2.6 Energy Efficiency7

2.6.1 Vehicle Technologies7

2.6.2 Building Technologies8

2.6.3 Industrial Efficiency8

2.7 Renewable Energy8

2.8 Hydrogen9

2.9 Nuclear Fission9

2.10 Nuclear Fusion10

3 Management & Coordination Recommendations..... 10

3.1 Develop, Publish, and Implement a U.S. Energy Innovation Strategy11

3.2 Improve Energy Policy Coordination Government-Wide11

3.3 Strengthen DOE’s Capacity to Manage an Expanded, Integrated Federal Energy RD&D Enterprise.....12

3.4 Create Mechanisms for Managing Both Demonstration Projects and High-Risk, High-Potential R&D12

3.4.1 Mechanisms for Pilot, Demonstration, and Early Commercialization Projects.....12

3.4.2 Mechanisms for High-Risk, High-Payoff R&D13

4 Policies To Expand Private Sector ERD&D Investment..... 14

5 International Cooperation Recommendations..... 15

6 Incentives For Large-Scale Deployment..... 16

6.1 Economy-Wide Carbon Constraints16

6.2 Sectoral Policies17

6.2.1 Electricity: Multiple Tools to Incentivize Low-Carbon Deployments17

6.2.1.1 Renewable Portfolio Standards18

6.2.1.2 Evaluating Loan Guarantees and Other Incentives for Low-Carbon Electricity Deployment.....18

6.2.1.3 Electricity Transmission and Distribution19

6.2.2 Vehicles: Efficiency Standards and Other Tools19

6.2.3 Buildings: Efficiency Standards and Other Tools22

7 Meeting The Energy-Innovation Challenge 22

Nomenclature.....23

References.....24

I INTRODUCTION

The incoming Obama administration and the 111th Congress face enormous challenges and opportunities in tackling the pressing security, economic, and environmental problems posed by the energy sector in the United States and worldwide.

- **Security challenges.** The world economy is critically dependent on energy supplies that originate in and transit through some of the most volatile regions of the world. Competition for control over and access to energy resources has long been a source of conflicts. Energy revenues help finance governments hostile to the United States. Energy infrastructure can be dangerously vulnerable to terrorist attack. Nuclear energy technologies, if not appropriately managed, can contribute to nuclear proliferation and be targets for terrorism. Accelerating global climate change—resulting in large part from energy use—may cause droughts, famines, and other catastrophes that undermine global security.
- **Economic challenges.** Volatile energy prices are having critical impacts on economies throughout the world. The United States is spending hundreds of billions of dollars a year on imported oil and imports a larger fraction of its oil than ever before. Moreover, the United States has lost its competitive advantage in the growing global market for technologies such as solar and wind energy. But response to the current financial crisis may create a once-in-a-generation opportunity to build toward a new energy economy that would create jobs and reestablish U.S. leadership in the critical global markets for clean energy technologies.
- **Environmental challenges.** Energy supply and end-use technologies are the main contributors to local and regional air pollution and global climate change, and major contributors to a wide range of other environmental problems. Addressing the accelerating climate problem is a critical challenge for human civilization in the 21st century.

Improving the technologies of energy supply and end-use is a prerequisite for surmounting these challenges in a timely and cost-effective way (Anadon & Holdren 2009).

The United States is the world's largest economy, the largest energy (and oil) consumer, and the largest historical contributor to the climate change problem. The United States still has the most capable scientific and engineering workforce in the world and has a lot to gain from the development and deployment of advanced energy technologies. In spite of this, the U.S. government has fallen short in what it can do to promote the development and deployment of advanced energy technologies.

President Obama has already signaled that he understands the importance of developing and deploying advanced energy-technologies. Just two weeks after winning the 2008 presidential election, he made the following statement (Obama 2008):

My presidency will mark a new chapter in America's leadership on climate change that will strengthen our security and create millions of new jobs in the process.

That will start with a federal cap and trade system. We will establish strong annual targets that set us on a course to reduce emissions to their 1990 levels by 2020 and reduce them an additional 80% by 2050.

Further, we will invest \$15 billion each year to catalyze private sector efforts to build a clean energy future. We will invest in solar power, wind power, and next-generation biofuels. We will tap nuclear power, while making sure it's safe. And we will develop clean coal technologies.

Accelerating the development and deployment of advanced energy-supply and end-use technologies will require leadership, alignment of policy incentives, consistency of policies, and patience on the part of government officials (Grübler 2009).

In the following sections, we outline our preliminary recommendations for near-term action to strengthen the U.S. effort to develop and deploy advanced energy technologies that can help meet the security, economic, and environmental challenges of energy at reduced cost. The budget recommendations in this paper are only for fiscal year (FY) 2010 and represent minimum levels based on ramping up from the FY 2008 levels where increases are most needed (and reducing effort where appropriate). They do not take into account the amounts provided in the recently approved economic recovery package. If the final package includes substantial funding for energy research, development, and demonstration (ERD&D) that will carry into FY 2010, the need for additional ERD&D appropriations in FY 2010 would clearly be reduced. The recommendations in this paper are based on literature reviews and preliminary assessments of the opportunities in each technological area. Later this year, we will publish more in-depth long-term recommendations informed by our ongoing analysis and additional expert elicitations.

Given the urgency of the effort to pull together the fiscal year (FY) 2010 budget proposal, we begin with our recommendations for the Department of Energy (DOE) budgets for energy research, development, and demonstration (ERD&D) activities. We then outline a number of broader steps to manage the energy-technology innovation effort and structure incentives for deployment of innovative energy technologies, to ensure that the nation gets the maximum benefits from its investment in ERD&D, and briefly discuss opportunities for international cooperation.

2 RECOMMENDATIONS FOR DOE'S RD&D BUDGET

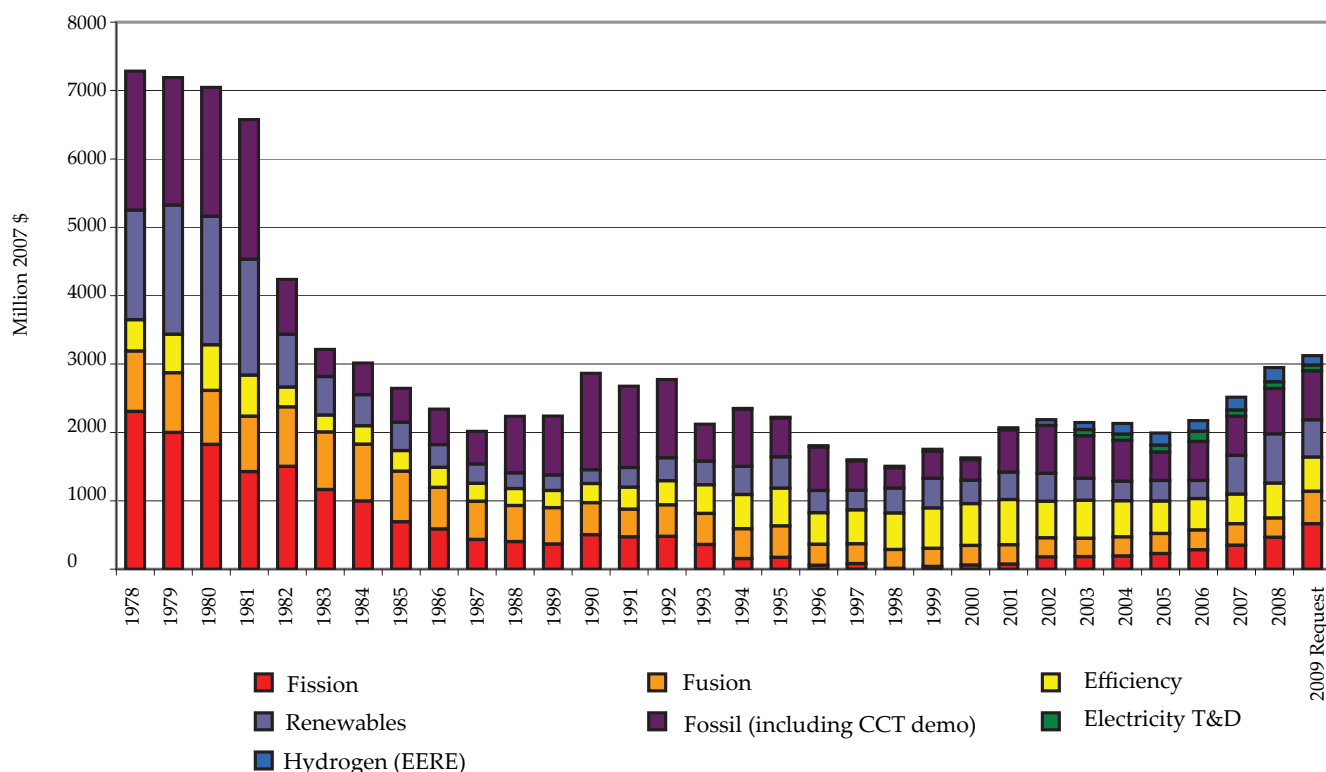
2.1 THE CONTEXT: KEY PLAYERS IN ENERGY RD&D

Before discussing recommendations for DOE's FY 2010 ERD&D budgets, it is useful to understand the context in which these ERD&D activities take place. Although U.S. government investments in ERD&D have increased somewhat in recent years, they remain far below the levels of the late 1970s, when the economy was far smaller (see Figure 1.) They are also well below what is likely to be needed to provide the improved energy technologies needed to meet the challenges of the 21st century or to maintain U.S. leadership in energy technologies as other countries increase their ERD&D investments (PCAST 1997, PCAST 1999, NCEP 2004).

Many government and private players in the United States invest in ERD&D, but DOE's role remains central. DOE is the largest government funder of ERD&D, and government support for RD&D in this area is critical to ensure adequate progress in all the areas that are too far from commercial application or too difficult for companies to capture the benefits of research and development (R&D) to motivate adequate private R&D, or where the private sector would underinvest in technologies that provide major public goods.¹ Beyond R&D, there is a critical need for government involvement in the demonstration and early-deployment stages, to help technologies across the "valley of death" between initial inventions and the point at which further development and deployment are attractive enough for the private sector to carry them forward itself (Gallagher, Holdren & Sagar 2006).

¹ For a recent account of the many other reasons that have contributed to inadequate private investment in energy-technology innovation, see Anadon and Holdren (Anadon & Holdren 2009).

Figure 1: U.S DOE Energy RD&D Spending FY1978 - FY2009 Request
(in millions of 2007\$)



Source: Gallagher 2008

Although the U.S. government's direct-funding role in the early stages of energy-technology innovation (ETI) is centralized around DOE, other agencies—including the Departments of Agriculture, Commerce, Defense, Interior, and Transportation and the Environmental Protection Agency (EPA), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA)—also have energy RD&D programs. By one estimate, for example, in FY 2006 agencies other than DOE spent about \$360 million in energy-related research, development, demonstration, and early deployment activities (CCTP 2006).² During that year, DOE spent \$2.1 billion in ERD&D, \$910 million in basic energy sciences (BES) research, and \$549 million in biological and environmental research (Gallagher 2008). Some other recent studies suggest that the role of agencies outside DOE is even smaller, perhaps because of differences in the definition of energy-related RD&D (EIA 2008).

State governments also play a significant role in the development and deployment of advanced energy technologies. The most recent estimate indicates that in recent years, state governments have invested as much in energy programs as DOE spent on ERD&D and BES combined, i.e. around \$3 billion, mainly on renewable energy and energy efficiency demonstration and commercialization programs (ASERTTI 2008, Terry 2009). The size of states' contributions to energy-related goals points to the importance of ensuring that federal agencies, in particular DOE, coordinate with the states. But state efforts, however laudable, are not a substitute for a coordinated national

² Expenditures in ERD&D by agencies other than DOE were taken from federal expenditures on the U.S. Climate Change Technology Program (CCTP) activities. CCTP's definition of the activities it includes, while focusing on technologies to reduce greenhouse gas emissions, encompasses the vast majority of the government activities focused on energy-related innovation.

ERD&D strategy. States will inevitably and rightly focus their efforts on state-specific issues and objectives, while the energy-related challenges the nation faces are national and even global in scope. Moreover, 50 individual state programs cannot bring to bear the critical mass of focused resources that the federal government can direct.

Beyond the federal government and the states, there is the most critical actor in energy-technology innovation—the private sector. Unfortunately, it is close to impossible to determine the size of its contributions to ERD&D on a technology-by-technology basis or overall.³ There are various reasons for this. For example, it is very difficult to determine what fraction of the substantial R&D expenditures by automobile companies and other manufacturers of energy-consuming goods can be counted as efforts to improve the energy-efficiency of these products.⁴ Information on private-sector expenditures in the early-deployment and widespread diffusion stages of ETI is easier to come by, as venture capital (VC) and private equity investments, asset finance projects, and corporate finance deals are announced by the main actors, and their transactions recorded by clean technology analysts, such as New Energy Finance (NEF) (NEF 2008). The lack of information about private sector activity in the early stages of ETI has not prevented (and should not prevent) the federal government from providing funds and other resources—mainly through DOE—to leverage private sector funds and expertise. We intend to provide a broad assessment of U.S. private-sector activity on energy-technology innovation later in 2009.

2.2 RECOMMENDATIONS FOR DOE'S BASIC ENERGY SCIENCES AND ERD&D BUDGETS FOR FY 2010

President Obama will need to submit the FY 2010 budget request for DOE. Table 1 summarizes our recommendations for the BES and ERD&D portions of this budget. We compare our recommendations with the funds appropriated for the same areas in FY 2008.

2.3 BASIC ENERGY SCIENCES

DOE's basic energy sciences (BES) activities are essential to improving and developing energy technologies. The FY 2009 budget request for Office of Science called for a funding increase from \$1.2 billion appropriated for FY 2008 to \$1.5 billion for FY 2010.

The Office of Science has engaged in extensive strategic planning exercises and created a series of "Energy Frontier Research Centers" to focus efforts in particular areas where breakthroughs could have high leverage in addressing key energy challenges. Given these initiatives to strengthen the focus and prioritization of the Basic Energy Sciences effort, and the clear need for fundamental research in the energy field, the Basic Energy Science program could put to good use an increase in funding of at least \$300 million from FY 2008. The NSF funding focused on scientific research related to energy challenges should also be expanded. DOE should establish new mechanisms to improve coordination between BES and the applied RD&D programs (PCAST 1997).

³ It is worth mentioning that industry also plays a role in funding university research. Although specific information for energy R&D is not available, in 2007, industry contributed 5.4 percent of all expenditures (\$49.4 billion) in science and engineering R&D at U.S. universities and colleges (Britt 2008).

⁴ R&D expenditures of utility companies, on the other hand, are relatively well documented. About 72 percent of the R&D investment of U.S. utilities—approximately \$300 million—was carried out in the Electric Power Research Institute (EPRI) (Chuang 2008).

**Table 1: FY 2010 DOE budget recommendations and rationale for change
from FY 2008 appropriations
(all figures in current million \$)**

Area	FY 2008 \$ Appropriation	Suggested \$ for FY 2010	Rationale
Basic Energy Sciences	1,177	1,500	<ul style="list-style-type: none"> - Future transformational technology innovations depend on today's basic science research efforts. - The Office of Science, which has been engaged in rigorous planning exercises, requested \$1.5 billion for FY 2009. We believe that it has the capacity to efficiently use \$300 million more than it received in FY 2008.
Fossil Energy	676	1,700	<ul style="list-style-type: none"> - In FY 2008, \$74 million were dedicated to FutureGen and \$119 million to the carbon sequestration initiative, but this investment is not nearly enough to demonstrate full-scale CCS technologies in several types of power plants and geologies. - An additional investment of \$1 billion would create the sort of investment needed to demonstrate CCS at commercial scale. - Much care must be taken to administer and manage these large investments.
Electric Transmission & Distribution	102	220	<ul style="list-style-type: none"> - Smart grid technologies will be central to ensure the future reliability and efficiency of the electric grid. DOE should create a smart grid R&D program with an initial funding of \$20 million. - DOE should also allocate \$100 million to the smart grid regional demonstration projects authorized by the Energy Independence and Security Act of 2007 (EISA).
Energy Efficiency	520	770	<ul style="list-style-type: none"> - The American Physical Society (APS) identified large opportunities in long-term research in building technologies (BT), vehicle technologies (VT), and energy storage. - Funding for FY 2010 should increase to at least \$770 million, increasing funding of the VT program by \$100 million, and the BT program by \$150 million.
Renewable Energy	730	850	<ul style="list-style-type: none"> - An increase of over \$120 million dollars—spread across the solar, wind, biomass, and geothermal programs—could serve as a first step for further exploiting opportunities in these areas before a long-term plan is developed.
Hydrogen (part of EERE)	211	220	<ul style="list-style-type: none"> - According to the 2008 APS report, there are more opportunities in the development of fuel cell technology than those being explored by the current hydrogen program within EERE. - We recommend a slight increase for EERE's hydrogen RD&D effort for FY 2010.
Nuclear Fission	472	350	<ul style="list-style-type: none"> - The focus of the Advanced Fuel Cycle Initiative, which received \$179 million in FY 2008, should be on long-term research to improve both open and closed fuel cycles. - The activities in the Nuclear Power 2010 program can be carried forward by the private sector, and federal support should be reduced.
Nuclear Fusion	287	450	<ul style="list-style-type: none"> - This would help bring the U.S. current on its contributions to ITER, while maintaining other fusion work. - This reflects the cancellation of Princeton stellarator. - Fusion should be seen as partly a pure science effort and partly a long-range energy R&D effort.
Total BES + ERD&D	4,173	6,060	- This represents a 45 percent increase.

2.4 FOSSIL ENERGY

Carbon capture from stationary sources of fossil fuel combustion and storage in geological formations has been identified by most analysts as an essential component of any comprehensive plan to reduce carbon dioxide emissions worldwide.

DOE started funding carbon capture and storage (CCS) from its Office of Fossil Energy in 2004. Since then, its efforts have grown rather quickly—in FY 2008 \$119 million were devoted to the carbon sequestration program and \$74 million were dedicated to the recently restructured FutureGen CCS demonstration project. But while the growth of these two programs has been impressive, this public investment is not nearly enough to demonstrate full-scale CCS technologies in several types of power plants using different capture and storage technologies in different geologic conditions. The private sector has little incentive to invest in CCS by itself; with no price on carbon emissions in place, capturing and sequestering carbon is simply an added cost—and there are significant policy and liability uncertainties surrounding CCS. Furthermore, the restructuring of FutureGen has created even more uncertainty about the future of CCS in the United States, and this uncertainty has stalled some of the efforts to push CCS technologies forward abroad, particularly in China. For these reasons, it is very important to provide more financial assistance for CCS demonstration projects and to articulate a clear strategy for demonstration of CCS early in the next administration.

The United States should support approximately 10 large-scale CCS demonstration projects (Schrage 2009, Kuuskraa 2007). These might be pursued in collaboration with other countries interested in CCS technology, as discussed below. According to an estimate by Professor Edward Rubin from Carnegie Mellon (Rubin 2008) a 5-year test of CCS technologies in a modern power plant would cost \$1 billion. Hence, a commitment of \$1 billion per year for approximately 10 years should be sufficient to demonstrate a range of capture technologies in a variety of geological environments and structures (Bielicki 2009). This commitment level should be regularly reviewed, however, as understanding of the technologies and the opportunities for cost-sharing through collaboration improve. As recommended by the CCS Reg project, a Presidential-Congressional Commission should monitor the experience of the demonstration projects and then recommend how to handle specific details on the basis of this experience (CCS Reg 2009). As a complementary effort, DOE should facilitate the dissemination of geologic data necessary to assess and estimate the potential CO₂ (and compressed air) storage capacity of geologic formations in the United States.

As discussed below, it is clear that new approaches are needed to manage large-scale energy-technology-demonstration projects, and this is no less true for CCS. Peña and Rubin (Peña & Rubin 2008), for example, have proposed creating a dedicated trust administered by a nongovernmental organization that would identify and fund needed CCS projects; ensure they are properly selected and managed; and deliver timely results that benefit everyone.

The Obama administration and Congress will have to determine whether this approach or some other option is the most effective way to manage such a CCS demonstration program—but it is clear that this management question will have to be resolved from the outset of the effort.

The European Union (EU) has recently committed to providing significant funding for CCS demonstration projects. In a memo released on December 17th, the EU indicated that 300 million allowances⁵ from the new entrants reserve of the Emissions Trading Scheme system “will be used to support up to 12 CCS demonstration projects and projects demonstrating innovative renewable energy technologies” (EU 2008). The memorandum also indicated that “a number of conditions are attached to this financing mechanism,” although information about these conditions has not yet

⁵ These allowances would be worth between \$6.1–\$12.2 billion if we assume that the value of one allowance is between 15€ (an underestimate of prices in early January 2009) to 30€ and that the euro/U.S. dollar exchange rate is \$1.36.

been released.⁶ It is time for the United States to make a significant commitment to accelerate the deployment of CCS technologies and consider cooperating with the other countries on key aspects of CCS technology innovation.

2.5 ELECTRICITY TRANSMISSION AND DISTRIBUTION

There is a broad consensus that major new investments in transmission and distribution are needed for reliable, cost-effective, and environmentally friendly electricity supply in the United States (DOE 2007b). DOE has been examining a range of technologies that could enable “smart grid” flows of electricity and information both to and from widely distributed producers and users, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances (DOE 2007a). The Energy Security and Independence Act of 2007 (EISA) directed DOE to create a smart grid research program to support modeling, the creation of standards, and research and implementation, but no funding was provided in FY 2008. The budget request for 2009 called for \$5 million. Given the importance of the issue, this initial request seems too small to develop the technologies and capacities needed. We recommend a \$20 million smart grid R&D program for FY 2010 as a beginning.

EISA also authorized up to \$100 million per year for five years for smart grid regional demonstration projects across the country, with the federal government providing up to a 50 percent cost-share for each project, but no funds have been appropriated to date. This program could ensure that the needs of different regions are being addressed when demonstrating new technologies, new systems, and new business models for smart grids.

2.6 ENERGY EFFICIENCY

In FY 2008, DOE allocated \$520 million for energy-efficiency programs within the EERE division. Drawing on findings by a recent report from the American Physical Society (APS 2008) focused on transportation and building efficiency, we recommend that funding for FY 2010 should increase to at least \$770 million, with an increase of \$100 million going toward the vehicle technologies program and an increase of \$150 million going toward the building technologies program.

2.6.1 VEHICLE TECHNOLOGIES

The APS report recommended that the vehicle technologies R&D program of DOE should be expanded in size and focus. A more balanced portfolio is needed across the full range of technologies to enable the deployment of potential medium- and long-range advances in automotive technologies. For example, increased research is needed in batteries for conventional hybrids, plug-in hybrids, and battery electric vehicles.⁷ This more balanced portfolio is likely to bring significant benefits sooner than the current program through the development of a more diverse range of efficient modes of transportation. Two areas of research, highlighted by the APS report, are particularly promising and should be given more attention.

The first is the development of better batteries and other energy storage technologies. These will be essential if electrification is to play a role in the transportation sector. In FY 2008, the vehicle technology program received \$213 million for FY 2008, of which \$48 million were devoted to energy storage within the hybrid electric systems subprogram. The APS study recommended that this pro-

⁶ The conditions for the granting of these allowances will be decided shortly by the EU Commission in close consultation with the EU Member States.

⁷ The APS report also recognizes more opportunities in the field of fuel cell technology. This is briefly covered in Section 2.8.

gram should be increased, focusing in particular on long-term R&D for batteries for electric vehicles with the required energy storage per unit weight and volume.

The second is research on reducing vehicle weight. This research should be expanded, as there is still significant potential for reduction. The APS study notes that if the goal of the FreedomCAR program was achieved, i.e. reducing weight by 50 percent, fuel economy would be significantly improved.

We recommend an increase in the budget for the vehicle technologies program from \$213 million in FY 2008 to \$300 million in FY 2010, focused on the areas just described.

2.6.2 BUILDING TECHNOLOGIES

The APS report (APS 2008) also recommended that DOE should sharply increase its R&D spending for next-generation building technologies, training building scientists, and supporting the associated national laboratory, university, and private sector research programs. The APS found that the near-term focus of DOE's building technologies program has resulted in insufficient long-term research (in particular in advanced ventilation, advanced windows, thermodynamic cycles, and ultra-thin insulators) and recommended restoring the funding for the building technologies program to its 1980 level—\$250 million in 2008 dollars—during the next 3 to 5 years from its current level of \$103 million.

Another area highlighted by the APS report was the need for a research, development, and demonstration program that makes integrated design and operation of buildings standard practice to achieve the 2030 zero energy building (ZEB) goal for commercial buildings.⁸ To achieve the goal of ZEB in hot, humid climates, DOE should also increase R&D expenditures to develop low-energy dehumidification and cooling technologies and strategies. The APS also recommended that DOE, state governments, and electric utilities should carry out the program cooperatively with funding from all 3 entities.

DOE should also follow through on its commitment to promulgate standards for all products for which it has been granted authority to do so. A streamlined procedure should be put in place to avoid delays in releasing the standards.

2.6.3 INDUSTRIAL EFFICIENCY

At this time we have no recommendations for the industrial efficiency program within DOE's Office of Energy Efficiency and Renewable Energy (EERE). We have assumed that the FY 2008 funding level of \$64.4 million will be maintained.

2.7 RENEWABLE ENERGY

The DOE budget for renewable energy RD&D has increased by a factor of 2.8 since its low in 2006, reaching \$730 million in FY 2008.

As highlighted by several recent reports, there are reasons to further expand the renewable energy program.

The wind energy program received \$50 million in FY 2008. There is room for technology improvement in all aspects of wind turbines, suggesting that a larger R&D program is needed. Recent

⁸ The ZEB goal is a building that uses no fossil fuels, replacing fossil fuels with renewables and reducing energy consumption by 70 percent relative to conventional buildings.

reports have also identified significant opportunities to lower development costs of geothermal energy by reducing the costs of drilling, power plant, and stimulation through public support for RD&D. MIT's Future of Geothermal report (MIT 2006) concluded that a \$300-400 million investment over 15 years would be needed to make early generation plants competitive. A more recent report by EERE (EERE 2008c) asserted that this conclusion is overly optimistic. Our preliminary recommendation is that DOE's geothermal program, which had a budget of \$20 million in FY 2008, should be expanded to at least \$30 million in FY 2010. Solar and biomass energy programs already receive the lion's share of DOE's investment in renewable ERD&D and are the subject of substantial private R&D investments as well, but given these sources' immense potential and the broad range of different technological approaches that are potentially promising in both solar and biomass, there is little doubt that a still larger effort would be worthwhile. As a complementary effort, DOE should prepare and publish a county-by-county assessment of U.S. biomass resources.

All told, at least \$120 million should be added to the FY 2008 budget, thereby providing \$850 million for the various programs in the renewable energy category for FY 2010. In some cases, there may also be a need for additional funding to support technology demonstrations (which tend to be expensive).

2.8 HYDROGEN

As described in the APS study, there are more opportunities in the development of fuel cell technology than those being explored by the current hydrogen program within EERE. For FY 2010, we recommend a modest increase of \$9 million for EERE's hydrogen RD&D effort.

2.9 NUCLEAR FISSION

Nuclear fission RD&D should focus on technologies that offer the potential for substantial improvements in the key factors that have limited nuclear power's potential as a broadly expandable energy option—cost, safety, security, proliferation-resistance, and waste management.

Nuclear fission received an estimated \$472 million in FY 2008 from DOE.⁹ About 38 percent of those funds, or \$179 million, were directed to the Advanced Fuel Cycle Initiative (AFCI). The AFCI supports the Bush administration's Global Nuclear Energy Partnership (GNEP) concept for a future nuclear world of fast-neutron reactors and reprocessing and recycling of the actinides from spent fuel; but there are strong reasons to believe that implementing that vision with any technologies likely to be available in the near term would pose more proliferation and terrorism risks and higher costs than would continuing with once-through use of spent fuel (NCEP 2004, Bunn 2007, MIT 2003, APS 2005, NRC 2007).

The 2007 National Research Council (NRC) review recommended unanimously that "the GNEP program should not go forward" (in the form of construction of large-scale facilities), and "should be replaced by a less-aggressive research program" (NRC 2007). In 2003, an MIT study (MIT 2003) called for a "major re-ordering" of DOE priorities and announced its "paramount recommendation" that, because "the open, once-through fuel cycle best meets the criteria of economic attractiveness and proliferation resistance," DOE should shift resources away from the "development of the more expensive closed fuel cycle technology involving reprocessing and new advanced thermal or fast reactor technologies." We reiterate our recommendation that GNEP funds should focus on

⁹ This excludes: the Mixed Oxide (MOX) program for plutonium disposition, which has little to do with developing technology for the future of nuclear energy; investments in maintaining the infrastructure at Idaho National Laboratory; and the portion of program direction funds estimated to be for those purposes. Total FY 2008 appropriations for the Office of Nuclear Energy from all accounts were \$1.034 billion.

long-term research on improving both open and closed fuel cycles (Anadon, Gallagher & Bunn 2008).

Another 28 percent of the FY 2008 fission RD&D budget, or \$134 million, went to the Nuclear Power 2010 program, a partnership with private industry to prepare new reactor designs for design certification and construction. As several of these designs are now moving toward design certification, and utilities are beginning to apply for licenses to build them, it should be possible for the reactor vendors and the utilities to carry the majority of the needed work forward from here. Federal support for this effort should be reduced, and any remaining federally-funded work should be limited to areas where a strong case can be made that the benefits of the work are not sufficiently appropriable by individual firms to give the private sector an incentive to pursue them.

Other areas that should be the focus of research include advanced technologies for designing in safeguards and security in future nuclear energy systems; small, exportable nuclear reactors suitable for the less-extensive grids in some developing countries; nuclear hydrogen technologies and other applications of nuclear power beyond electricity generation; advanced modeling and simulation capabilities; and in-depth assessments of total world uranium resources likely to be recoverable at different prices in the future. With a reduced focus on reprocessing and fast reactors, a reduced focus on designs the private sector can carry forward, and modest increases in several areas, we recommend that the \$472 million FY 2008 figure be reduced to \$350 million for FY 2010.

2.10 NUCLEAR FUSION

For FY 2009, the Bush administration requested a substantial increase in fusion R&D funding, from \$286.5 million to \$493.1 million. This was necessitated in part because Congress's FY 2008 omnibus appropriation cut nearly all of the U.S. contribution to the International Thermonuclear Experimental Reactor (ITER), and substantial funds were therefore needed in FY 2009 to fund the U.S. ITER contribution. The continuing resolution keeping funding for federal programs at FY 2008 levels through March 2009 is likely to be a significant problem for U.S. contributions to ITER. Continued ITER funding will be needed in 2010; the amount will depend in part on how much Congress provides for FY 2009 in the final omnibus appropriation. With the cancellation of the National Compact Stellarator Experiment (NCSX) and assuming that it will not be necessary to fund more than a single year's ITER contribution, it should be possible to maintain an effective fusion program with a budget in the range of \$450 million.

As the National Ignition Facility moves toward initial operations, funded by DOE's defense programs, the administration and Congress should provide sufficient funding so that civilian fusion efforts can take full advantage of this new facility for civilian programs as well.

Fusion energy will not provide commercial electricity for decades to come. But the array of low-carbon energy technologies available is not so broad that it makes sense to decide today that fusion energy will not be needed in the future. Today's fusion work is justified in part by its long-term energy potential, and in part as a pure science activity, advancing the boundaries of high-energy plasma physics. Indeed, it is funded out of DOE's Office of Science, not DOE's Office of Nuclear Energy.

3 MANAGEMENT & COORDINATION RECOMMENDATIONS

Several actions, some of which have already begun, should be taken as soon as practicable to improve the effectiveness of U.S. investments in energy-technology innovation.

3.1 DEVELOP, PUBLISH, AND IMPLEMENT A U.S. ENERGY INNOVATION STRATEGY

Just as there is no technological “silver bullet” that will solve all the energy-related problems that the United States faces, there is also no single policy “silver bullet” that will lead to a transformed energy system by itself. Rather, a comprehensive strategy is needed that integrates a wide range of policy tools to address the energy challenges facing the United States.

Such a coherent national strategy would include the entire energy-innovation chain, integrating support for basic research on breakthroughs that may enable the energy technologies of tomorrow; applied research and development to bring new technologies to the point where they are ready for large-scale demonstration; demonstration projects; and incentives for early deployment and for widespread market diffusion. The strategy should balance the roles of government, the private sector, and the U.S. strategy for managing cooperation and competition internationally.

The absence of such a comprehensive energy-innovation strategy has too often meant that different parts of the U.S. government have supported different energy technologies at different times, with inadequate coordination and follow-through. For too many years, DOE has conducted R&D almost in isolation from demonstration and deployment policies, which are usually enacted by the Congress—leading, in many cases, to technologies failing to make it over the barriers to widespread commercial deployment. To meet today’s energy challenges, an integrated approach is essential.

The system for energy innovation is complex, non-linear, and iterative; the idea that there can be a logical separation between policy for energy R&D versus energy deployment policies (or between supply-push and demand-pull in technology) is inaccurate and obsolete. The forces and signals that might lead a new and improved energy technology from invention to eventual adoption all interact. Coordination not only among federal agencies but with private industry, both parties in Congress, states, universities, and other stakeholders will be critical in forging and implementing such an integrated approach.

3.2 IMPROVE ENERGY POLICY COORDINATION GOVERNMENT-WIDE

Vastly improved coordination of energy policy across the federal government is badly needed. The current effort is highly fragmented, distributed, and often working at cross purposes. President Obama took an important first step in this direction in mid-December 2008, announcing the creation of a White House Coordinator for Energy and Climate Change. Obama and his team will have to consider carefully what roles this new coordinator, DOE, the Office of Science and Technology Policy, and other relevant agencies and departments should play in coordinating the government’s overall energy-technology innovation effort.

Those coordinating the ETI effort should have the authority to establish an overarching energy-innovation strategy for the United States, should convene advisors from the federal agencies and White House offices that have energy as part of their portfolios as well as from the private sector, and should assemble such information as is needed for the president to craft a coordinated and comprehensive energy policy. They should also help to coordinate the efforts in the various federal agencies to implement the president’s policies in a coherent manner and to work with Congress on necessary legislation to realize an effective national effort to improve the energy system.

An example of the benefit of coordinated policy can be seen in the history of the development of unconventional sources of natural gas. The Gas Technology Institute (GTI, formerly the Gas Research Institute) conducted sustained research on all aspects of natural gas. Coal-bed methane was once a nuisance and a safety hazard to be vented to the atmosphere; research by GTI developed

the technology to collect it in usable form before market conditions demanded new sources. When incentives for unconventional natural gas were enacted in the 1980s, the technology was ready to be deployed, which enabled smooth adoption into the market. The result is that coal-bed methane is now 7.5 percent of U.S. production.¹⁰ Neither the research nor the incentives would have worked alone, only the correct sequence of policies was effective.

3.3 STRENGTHEN DOE'S CAPACITY TO MANAGE AN EXPANDED, INTEGRATED FEDERAL ENERGY RD&D ENTERPRISE

Because of the complexity of the system for innovation in energy technology, the management structure that supports energy innovation is as important as funding level. To maximize the effectiveness of U.S. investments in energy innovation, the Obama administration should forge new approaches to managing the effort at DOE, focusing on a portfolio approach that includes a broad set of energy technologies at many stages of technological development. This must include expanded information-sharing between different energy innovation efforts, more effective coordination of programs with the private sector, and full integration with the presidential-level strategy for energy-technology innovation, using the full set of policy tools to support technologies from basic research to commercial deployment. This should include a proactive approach to public-private partnerships that integrates projects into an energy-technology strategy, rather than simply waiting for private-sector applications for technology transfer. The goal of all these management changes should be greater strategic coherence and communication across agencies rather than new layers of bureaucracy.

3.4 CREATE MECHANISMS FOR MANAGING BOTH DEMONSTRATION PROJECTS AND HIGH-RISK, HIGH-POTENTIAL R&D

Both of these classes of innovation call for funding and management structures that do not exist within DOE today.

DOE and its laboratories have been successful at R&D, but do not have as strong a record in managing demonstration and deployment programs. To accelerate innovation, the United States needs to match increased resources with a strengthened capacity to use them strategically, a structure to treat commercialization-stage projects more like commercial projects, and a means of taking on long-term, risky, and cross-disciplinary projects.

3.4.1 MECHANISMS FOR PILOT, DEMONSTRATION, AND EARLY COMMERCIALIZATION PROJECTS

Pilot, demonstration, and commercialization stage innovation requires procurement, funding, and decision rules similar to those of private sector enterprises, so that information about genuinely commercialized technology is generated to inform policymakers and the business community (Ogden, Podesta & Deutch 2008).

In contrast, DOE's past record is marred by three infamous demonstration projects: FutureGen, the Synthetic Fuels Corporation, and the Clinch River Breeder Reactor. In 2008, with construction of the proposed FutureGen coal power plant with carbon capture and sequestration still years away and costs increasing, the Secretary of Energy pulled funding for FutureGen and attempted to restructure it with the more modest goal of equipping existing plants with carbon capture systems. The Synthetic Fuels Corporation sought to develop coal-to-liquids technologies at a time when the

¹⁰ www.gastechnology.org

market would not support the technology's costs. Both projects suffered from overly optimistic predictions of cost and performance, overly ambitious scale given the state of the technologies, and dependence on business practices that were not credible in the private sector (Ogden, Podesta & Deutch 2008). The Clinch River project similarly suffered massive cost overruns and lack of private-sector interest; ultimately Congress pulled the plug on continued funding. Unfortunately, these experiences—especially the recent FutureGen episode—appear to have made DOE reluctant to support large-scale demonstrations, just when such demonstrations are needed to pave the way for commercialization in several areas of energy technology. A new management structure for such efforts is clearly required.

The approach taken by the research consortium SEMATECH for semiconductor manufacturing technology is a positive example for a technology enterprise. From its founding, SEMATECH has had norms of open information flow, low hierarchy, and participation. Meetings function as group problem solving sessions rather than data transmission; project teams are formed across specialties and member firms (Browning, Beyer, & Shetler 1995). Project decisions are made based on strategic planning and the reports of technical advisory boards rather than on government direction or the interests of member firms. Projects fit into a long-horizon roadmap of the technological needs of the industry (Carayannis & Gover 1997). The management style and strategic planning were a major contributor to SEMATECH's success in transforming semiconductor manufacturing technology (Beyer & Browning 1997, Macher, Mowery, & Hodges 1998). SEMATECH was sufficiently successful that after U.S. government funding ended in 1996, private companies continued the effort, expanding it to an international consortium.

Ogden, Podesta, and Deutch (2008) have proposed a new approach focused on the establishment of an independent Energy Technology Corporation (ETC), which would be responsible for working with the private sector to implement energy-technology demonstration and commercialization projects. The ETC would be a government-owned corporation, acting on corporate principles but susceptible to government instruction.

3.4.2 MECHANISMS FOR HIGH-RISK, HIGH-PAYOFF R&D

In addition to large-scale demonstration and commercialization projects, there is also a need to support high-risk, high-payoff R&D at the earliest stages. Radical innovations often (but not always) develop outside the linear mode of research-development-deployment and involve new bundles of performance metrics that do not initially compare well to existing technology (Fri 2003). There have been several proposals for an Advanced Research Projects Agency for Energy (ARPA-E) (CA-CP 2008) modeled on the Defense Advanced Research Projects Agency (DARPA), which has been highly successful in sponsoring such high-risk, high-payoff projects related to military technologies. (The internet, among other technologies, originated in DARPA-sponsored work.) Critical elements of the DARPA model include institutionalizing approaches that allow managers to take high risks, that focus on technological breakthroughs to achieve particular sharply defined missions, and that bring the technology up to the level of a prototype that more traditional development organizations can then carry forward.

The Energy Frontier Research Centers (EFRCs) created by DOE's Office of Science are DOE's current approach to focusing fundamental research in high-payoff areas. These centers bring together the skills and talents of multiple investigators to enable research of a scope and complexity that would not be possible with the standard individual investigator or small group award. EFRCs are expected to be in the \$2–5 million range annually for an initial 5-year period. Their objective is to tackle the "Grand Challenges" outlined by the Basic Energy Sciences Advisory Committee (BE-SAC). These centers, however, focus on an even more fundamental stage of research than is envi-

sioned for ARPA-E and are not at a scale where they would be able to make rapid progress toward proof of principle of transformational energy technologies.

Whatever approach is taken, such transformational research will require mechanisms to tolerate and learn from failure, so that project leaders will be willing to take risks and be highly experimental. In addition, both demonstration efforts and transformational research will require good management with clear objectives; stable, long-term funding for finite, discrete products; and mechanisms that enable and do not punish cutting losses by ending projects when appropriate.

4 POLICIES TO EXPAND PRIVATE SECTOR ERD&D INVESTMENT

Already, venture capital and other private investments in energy research and development have surged in recent years, responding to increasing concerns over oil and gas prices and climate change (including the expectation that the government will impose a substantial price on carbon emissions in the future, discussed below). A broad range of government policies can help leverage additional private investment in R&D on energy technologies that can help address U.S. and global economic, security, and environmental challenges. A more detailed paper on encouraging private ERD&D investments will be published later, but a few preliminary thoughts are discussed here. (Policies relating to incentives for deployment are discussed below.)

The most important government policy to encourage such private investments is getting the prices right: if private firms are confident that substantial and lasting carbon prices will be imposed, they will be motivated to develop technologies that can avoid carbon emissions at lower cost. Similarly, if the full social costs of the use of imported oil were included in prices, private firms would be motivated to invest additional resources in developing cost-effective alternatives.

Tax credits for R&D investments are another important tool by which the government should incentivize additional private sector R&D. The National Research Council committee that produced the report *Rising Above the Gathering Storm* (NAS 2005), the Information Technology & Innovation Foundation (Atkinson 2007), and the U.S. Chamber of Commerce (USCOC 2003) have all recommended making the current research and experimentation (R&E) tax credit permanent and expanding it to cover a larger fraction of the costs of R&D.

There are two main arguments in support of these recommendations. First, a permanent credit offers more predictability for private investors (particularly critical for multi-year projects), and preliminary evidence suggests that this makes the credits more effective in incentivizing investments. The most comprehensive study on the effectiveness of R&D tax credits indicates that a 10 percent drop in the cost of R&D stimulates a 1 percent rise in the level of R&D in the short-run and nearly a 10 percent rise in R&D in the long-run (Bloom, Griffith & Van Reenen 2002).¹¹ Second, the United States has fallen behind the governments of other Organization for Economic Cooperation and Development (OECD) countries in providing support for R&D in the private sector. In the late 1980s, the United States had the most generous tax treatment of R&D in the world; by 2004, the United States had fallen to 17th in generosity (Atkinson 2007, Warda 2006). Increasing the R&E tax credit from 20 percent to 40 percent, as recommended in *Rising Above the Gathering Storm*, would make U.S. tax treatment of R&D competitive again with the approach in other OECD countries, stimulating additional R&D.

Thus, we strongly support expanding and making permanent the R&E tax credits. If problems of defining what technologies are covered can be overcome, there is also a case for expanded tax

¹¹ This study used panel data from 9 OECD countries over 19 years. In estimating the cost of R&D through time in the various countries, the paper accounts for depreciation allowances, tax credits, statutory tax rates, and real interest rates.

credits for investments in R&D on innovative energy technologies to address key security, economic, and environmental challenges. In addition, the U.S. government should also award tax credits to U.S. firms participating in demonstration projects built in other countries, as recommended by the 1999 PCAST report (PCAST 1999).

Appropriately managed public-private partnerships, sharing costs of R&D between the government and the private sector can also help increase private-sector investments in targeted areas. The SEMATECH consortium to develop new approaches to semiconductor manufacturing, described earlier, is a good example of such a successful public-private partnership. Expanded use of public-private partnerships should be one element of the comprehensive energy innovation strategy recommended above.

5 INTERNATIONAL COOPERATION RECOMMENDATIONS

Through international cooperation in ERD&D, the United States can share the costs, risks, and resources required for basic scientific research or long-term propositions (e.g., fusion); increase the utilization of facilities; reduce the costs of emerging technologies through accelerated learning; share costs for RD&D on technologies that are expected to provide public benefits (e.g., CCS technologies); promote the development of innovative capabilities at home and abroad to promote long-term competitiveness; promote interaction and discussion within partner countries; and develop mutually acceptable solutions to common problems (e.g., reducing the transport of airborne particulates) (Gallagher, Holdren & Sagar 2006). But most importantly, the macroeconomic, environmental, and national-security risks to the United States in the energy domain—which correctly preoccupy the federal government—cannot be successfully addressed by U.S. actions alone, making international cooperation—especially with major emerging economies and emitters such as China and India—critical to facing the new energy challenges (Gallagher & Holdren 2004). At the same time, international cooperation involves significant transaction costs, issues related to intellectual property, and other barriers and constraints.

The United States has a wide range of international agreements through multilateral and bilateral partnerships in the energy sector. These agreements include the participation of governments, international organizations, private industries, universities, and nongovernmental organizations. This wide variety of uncoordinated agreements makes it very difficult to map the international cooperation landscape and to determine what is being accomplished by the international effort.

The next step for the United States is to create a coherent and expanded strategy for engaging in international cooperation on energy technologies with OECD countries and with the large emerging economies. Our specific recommendations about projects and partnerships will be forthcoming later in 2009 and will include expanded cooperation with both developed countries and major emerging economies such as China and India.

As examples of this ongoing area of research, some of our upcoming recommendations that relate specifically to cooperation with China are listed below. We recommend a substantially expanded energy-technology cooperation program with China, especially on clean and efficient vehicles, renewables, efficiency, advanced coal, and carbon capture and storage technologies, including:

- Since China is second only to the United States in terms of energy consumption, and it has now surpassed the United States as an emitter of greenhouse gases, President Obama should make an early trip to China with energy and climate change high on the agenda. During this trip, the president should establish a framework for cooperation on ERD&D, signal that climate change is a top priority, and develop a plan for enhancing U.S.-China oil security as major oil consumers.

The Obama administration should then initiate a high-level meeting as soon as possible with Chinese counterparts (e.g. the U.S. Secretary of Energy, the White House Energy and Climate Coordinator, the U.S. Science Advisor, the Chinese Minister of Science and Technology, and the President of the Chinese Academy of Sciences) to discuss expanded energy cooperation.

- The United States should launch a major cooperative effort in CCS with China, designed to develop and demonstrate, both in the United States and China, the technologies to begin capturing carbon at a large scale within a decade. Deployment incentives will be needed as well.
- As a first step, the development and deployment of Integrated Gasification Combined Cycle (IGCC) power plants with CCS in the United States and China should be added to the U.S and China Fossil Energy Protocol.¹² Alternatively, the two countries could establish cooperative projects related to IGCC with CCS through other high-level official mechanisms, such as the Strategic Economic Dialogue. The most important point is that cooperation on advanced coal technology combined with CCS should be established under the auspices of an official agreement between the U.S. government and the Chinese Ministry of Science and Technology.
- The two countries should establish a “U.S.- China Center for Clean Power Innovation.” Initially, the Center could work on design and operation standards for IGCC, policies to enable CCS demonstration and deployment, and creating working relationships through visiting scholars and exchange students. After the initial stages, the Center could establish a joint pilot plant with participation from universities, research institutes, and the private sector from both countries. This second stage of the Center’s existence could also continue to analyze effective deployment policies.
- The United States and China should also establish new cooperation mechanisms and detailed proposals on advanced vehicles and batteries, renewables, and efficiency, possibly through the U.S.-China EERE Protocol.

6 INCENTIVES FOR LARGE-SCALE DEPLOYMENT

Developing new energy technologies is not enough. To have an impact on the energy challenges of the 21st century, new energy technologies must not just be invented but be widely deployed. Hence, as discussed above, an integrated national energy strategy is needed, covering the entire innovation chain, from basic research to commercialization.

6.1 ECONOMY-WIDE CARBON CONSTRAINTS

Fundamentally, private firms will not deploy low-carbon technologies on the scale required until they have a profit incentive to do so. The most important single step toward commercialization of low-carbon technologies is to put a price on carbon emissions. The U.S. climate policy could make use either of carbon-equivalent taxes or a cap-and-trade system. A tax approach would provide greater price predictability, facilitating energy investments (Gallagher 2009, Metcalf 2007), while a cap-and-trade system would provide greater certainty on emissions levels. Politically, a cap-and-trade system appears to have advantages; the European Union has implemented a system based on cap-and-trade, and all major U.S. legislative proposals currently being debated are based on cap-and-trade as well.

¹² None of the five annexes of the protocol focus explicitly on coal power: Annex I focuses on Power Systems, Annex II on Oil and Gas, Annex III on Clean Fuels, Annex IV on Energy and Environment Technologies, and Annex V on Climate Science. As of 2006, only two activities related to IGCC or CCS had been carried out under the agreement: a tour of an IGCC facility under Annex I and a study of CO₂ sequestration by spraying aqueous ammonia under Annex IV (DOE 2006).

A predictable price for GHG pollution would stimulate innovation in low-carbon technologies, reduce policy uncertainty for private investors, motivate other countries, and enable the United States to credibly engage in global discussions on climate change. In addition, a national-level climate policy would correct some of the inefficiencies of having different regional climate policies, reducing overall compliance costs.

The country and the world cannot afford to wait for a “perfect” approach to GHG emissions reductions—i.e., one that satisfies all stakeholders. Instead, the GHG-reduction policy should have built-in flexibilities to adapt to future economic, environmental, and technological information. In particular, the system should be designed to become more stringent over time.

We advocate setting a long-term atmospheric concentration goal for greenhouse gases, bearing in mind that the goal may need to be revised in light of new scientific information. Once this goal has been established, an emissions budget for the United States can be created, and policies designed with a view to meeting the budget goal (Gallagher 2009). President Obama has stated that his goal is to reduce U.S. emissions at least to their 1990 levels by 2020 and to reduce them an additional 80 percent by 2050. Some climate scientists have indicated that the world might need to move still faster in reducing emissions to avoid “a possibility of seeding irreversible catastrophic events” (Hansen et al. 2008).

6.2 SECTORAL POLICIES

Policies that put a suitable price on carbon are necessary, but are not likely to be sufficient. A variety of market imperfections have historically meant that even steps such as building efficiency measures that would pay for themselves in the long-term are not broadly adopted. Targeted policies in several particular sectors are likely to be needed to shift the energy system onto a trajectory that reduces emissions and improves security as rapidly as required. In some areas, such as investments in efficiency and in mass transit projects that are already approved and ready to move forward, such sector-specific policies can also lead to rapid job creation as part of a “green recovery” effort; indeed, the recovery package currently being considered includes billions in efficiency-related investments.

6.2.1 *ELECTRICITY: MULTIPLE TOOLS TO INCENTIVIZE LOW-CARBON DEPLOYMENTS*

Carbon prices alone are not likely to be enough—at least initially—to motivate deployment of low-carbon electricity sources at the pace and scale required to address the climate challenge. A variety of additional government policies can help encourage early commercialization and widespread deployment of low-carbon electricity technologies.

Past approaches have often allocated government support only to certain selected technologies, rather than seeking balanced support for any technologies that can meet the policy objectives. Future policies should, to the extent practicable, structure support for deployment of new technologies in ways that are neutral among different technologies to achieve the policy objectives, rather than attempting to have government pick the best technological options. Some technologies, however, may require targeted government support at different stages of innovation in order to overcome market biases or barriers, some of which may have been created by past government rules, regulations, and subsidies. A certain path-dependence has already been created, with a great deal of infrastructure built to serve the energy technologies of the past. Overcoming this “lock-in” sometimes requires supporting certain technologies more than others. Below, we discuss several particular approaches to encouraging deployment of low-carbon electricity sources that have received support from Congress, President Obama, or other groups in recent years.

6.2.1.1 RENEWABLE PORTFOLIO STANDARDS

Many states have adopted so-called “renewable portfolio standards” (RPS) that require that specified fractions of electricity be produced from renewable sources such as solar and wind. President Obama has argued for a national RPS that requires utilities to increase the share of renewable electricity generation to at least 10 percent by 2012 and 25 percent by 2025. Recent studies indicate that the goal of 25 percent by 2025 would be challenging to meet without significantly increasing consumer costs, but is likely to be achievable if major technological progress is forthcoming (RAND 2008). Lower percentages or longer time-lines might not be very effective at harmonizing state RPS policies—in 2007, 16 states already had targets that would require utilities to obtain approximately 20 percent of their electricity from renewable sources by 2020 (Wiser & Barbose 2008).

State RPS policies have proven effective in encouraging renewable energy generation. A study by the Lawrence Berkeley National Laboratory estimated that from 2001 through 2007, roughly 65 percent of the total wind additions in the U.S. were motivated, at least in part, by state RPS policies. In 2007 alone, 76 percent of non-hydropower renewable capacity additions took place in states with RPS policies (Wiser & Barbose 2008).

RPS policies have been criticized for legislating fixed percentages of particular technologies without attempting to use market mechanisms to pursue the lowest-cost options for reducing emissions. Supporters have responded that RPS policies have been an effective way to achieve multiple goals that are not reflected in market prices, including reducing carbon emissions, reducing emissions of other pollutants, diversifying electricity portfolios, and providing electricity production that is more sustainable for the long haul. Given that many states are putting RPS approaches in place, with widely differing standards and enforcement (Wiser & Barbose 2008), some electricity generation firms would prefer a national RPS specifying a single national approach to attempting to meet large numbers of different state standards.

As a key goal of such standards is to reduce GHG emissions from the electricity system, some analysts have argued for a broader approach that does not favor some low-carbon technologies over others (Apt, Lave & Pattanariyankool 2008). A “low-carbon portfolio standard,” for example, would allow utilities to also use new nuclear plants or plants with carbon capture and sequestration to meet the requirement. The Obama administration and Congress will have to determine whether such a broadening of the RPS is desirable, and, if so, whether the portion of electricity coming from such sources should be adjusted.

6.2.1.2 EVALUATING LOAN GUARANTEES AND OTHER INCENTIVES FOR LOW-CARBON ELECTRICITY DEPLOYMENT

Low-carbon electricity sources tend to be capital-intensive, making them more costly to finance in deregulated electricity markets where the risk to investors is higher. Some technologies, such as nuclear power, pose unique risks arising from the high concentration of energy and potential toxicity in the reactor core, and the initial deployments of plants with new designs. Some technologies may also require government subsidies to be cost-competitive, until additional R&D and learning brings their costs down in the future. Several government policies have been enacted or proposed in recent years to address these issues.

One approach is to offer government loan guarantees, making such projects less costly to finance. Title XVII of the Energy Policy Act of 2005 authorizes DOE to issue loan guarantees for energy projects that fulfill certain criteria, and the FY 2008 Omnibus Appropriations Bill authorized \$38.5 billion in DOE loan guarantees. The legislation specified particular amounts of guarantees available for energy projects falling under ten categories, going beyond electricity to cover other

energy sectors as well. The categories included: renewable energy; advanced fossil (including IGCC); hydrogen fuel cells; advanced nuclear; CCS; efficient electrical generation, transmission and storage; efficient end-use technologies; fuel efficient vehicles; pollution control equipment; and refineries. These guarantees would effectively transfer large parts of the risk in such projects from investors to taxpayers, reducing financing costs (though the firms receiving the guarantees would pay the government its estimated cost of bearing this risk).

Loan guarantees are by no means the only approach to encouraging deployment of low-carbon electricity technologies. Production tax credits (which offer a reduction in taxes for each kilowatt-hour produced and sold) and investment tax credits (which offer a reduction in taxes for investment in particular technologies, even if the investment fails to lead to production) have been very important in encouraging deployment of wind and solar technologies in the United States. A variety of other methods for managing the risks of such projects also exist, including long-term power purchase agreements, rate-base regulation, feed-in tariffs guaranteeing that low-carbon sources will get a particular price for their power, and more.

Given the need to deploy large numbers of low-carbon facilities and the huge investments likely to be required, it is important to find approaches that provide the greatest incentives for deployment at the lowest costs to taxpayers and ratepayers. We recommend that the Obama administration undertake an in-depth evaluation of the most effective approaches to encourage deployment of low-carbon technologies.

6.2.1.3 ELECTRICITY TRANSMISSION AND DISTRIBUTION

Widespread deployment of low-carbon electricity sources is likely to require major investments in modernizing U.S. transmission and distribution systems—both to bring power from where the wind or solar resources are or where a nuclear power plant can be safely located to where the loads are, and to integrate intermittent and often distributed sources like solar and wind into the electricity system in an efficient way. Moreover, major investments in transmission and distribution will be needed just to remedy weaknesses in the existing system and allow it to keep up with demand, which in a reference scenario is projected to grow by 39 percent from 2005 to 2030 (EERE 2008a).

As noted above, the 2007 EISA authorized federal funding for a portion of the cost of “smart grid” deployment projects, but no funding has yet been appropriated. A recent study by researchers at the Center for American Progress (CAP) (Hendricks & Goldstein 2008) recommended funding of roughly \$1 billion in 2009, which they estimated would allow over one million houses and businesses to be integrated into a utility-level operating system. Some federal investment in modernized transmission and distribution is needed, but the precise level of commitment should be flexible and frequently re-evaluated, given the lack of federal experience in this type of investment.

The new administration should commission a study on how best to incentivize the needed investments in transmission and distribution and whether FERC or a new entity is best suited to coordinate the effort.

6.2.2 VEHICLES: EFFICIENCY STANDARDS AND OTHER TOOLS

Reducing oil consumption and carbon emissions from the U.S. vehicle fleet is likely to require a range of policies in addition to carbon prices (Gallagher & Collantes 2008). Some of the efforts that should be considered include: (a) replacing Corporate Average Fuel Economy (CAFE) standards with carbon dioxide emission standards for passenger vehicles and heavy-duty trucks; (b) creat-

ing a “feebate” system¹³ to promote the purchase of efficient vehicles; and (c) setting a floor on oil prices, once the current economic crisis has receded, in order to create incentives for consumers to purchase fuel efficient products and to reduce the significant uncertainty that private investors face when considering clean technology investments (Gallagher & Collantes 2008, Lee 2009). Others have advocated a federal mandate that would require that increasing fractions of vehicles sold be capable of running on either gasoline or biofuels, or be plug-in hybrids, to reduce the continuing commitment to a gasoline-powered system represented by the sale of millions of new gasoline-powered vehicles every year (Woolsey & Korin 2008).

Government policies focused on urban sprawl, mass transit, and rail services can also have a major impact on reducing oil consumption and emissions from the U.S. transport sector (while creating additional jobs and reducing the transportation burden on the neediest). The opportunities in the following areas should be evaluated in terms of their cost-effectiveness and the speed at which they can be executed: expanding bus and subway services; reducing public transportation fares; increasing federal support for state and municipal transit operation and maintenance budgets to deal with increased ridership; increasing federal subsidies for employer-based mass transit incentives; and increasing funding for critical mass transit programs currently bottlenecked by lack of funds (Pollin 2008).

Over the longer term, the administration and Congress should provide the funds needed for the Department of Transportation (DOT) to expand the U.S. high-speed intercity rail infrastructure.¹⁴

6.2.3 BUILDINGS: EFFICIENCY STANDARDS AND OTHER TOOLS

In addition to expanding the RD&D effort, the American Physical Society report (APS 2008) recommended several complementary federal policies to accelerate the diffusion of energy-saving building technologies. Some of these policies have been listed below.¹⁵

- States should be strongly encouraged to set standards for residential buildings and require localities to enforce them. For commercial buildings, performance-based standards that rely on computer software to compare a building design with a reference building are implemented only in California. The federal government should develop a computer software tool much like that used in California to enable states to adopt performance standards for commercial buildings. States should set standards tight enough to spur innovation in their building industries.¹⁶
- Demand-side management (DSM) programs in which a central agency, often a utility company, invests money (in education programs, in rebates to encourage customers to buy more efficient appliances, or in direct upgrades) to assist customers in becoming more energy efficient have proven effective. Where DSM programs do not exist, the federal government should encourage states to initiate them through utility companies. The APS suggested that the federal role could be to provide rewards to states that have significant and effective DSM programs and disincentives to those that do not.

¹³ Feebates are essentially a green tax on the acquisition stage of a vehicle and are aimed at shaping consumer demand. Because they are sales tax incentives, they are more effective than income tax incentives—they are immediate and easy to obtain.

¹⁴ On December 16, 2008, the Federal Railroad Administration requested “Expressions of Interest in Implementing a High-Speed Intercity Passenger Rail Corridor”. Although authorized, no funds have been appropriated to support implementation of high-speed rail under this initiative, and the availability of such funds in the future is not known (DOT 2008).

¹⁵ The APS recommendations on demand-side management (DSM), appliance standards, and building codes are mainly based on the successes of those programs in California.

¹⁶ The California Energy Commission has estimated that a good nationwide program to enhance energy code enforcement would cost about \$50 million annually. If this program succeeded in improving energy performance in new construction by only 10 percent, it would save about \$300 million per year.

Retrofitting the country's privately-owned commercial and residential buildings also presents an opportunity to create jobs and help mitigate U.S. energy-related challenges. The U.S. government should expand its efforts to overcome the market-failures associated with cost-effective home-efficiency improvements.

A variety of initiatives could be expanded or created to encourage the retrofitting of privately-owned and commercial buildings. One example of an initiative that could have a quick impact is expanding the energy efficiency tax credit program. This tax rebate program is administered by the EPA and the Internal Revenue Service, and it has a cap of \$500 million and a maximum of \$2,000 per household for qualifying energy-efficient products. Researchers at the CAP have recommended expanding the tax-credit to \$5 billion, which they estimate would allow some 2.5 million homes to benefit from the cost reduction in energy-efficiency retrofits (Pollin et al. 2008).

CAP has also recommended substantially expanding the Weatherization Assistance Program (WAP). Through WAP, the federal government finances efficiency improvements in homes of low-income families, thereby creating jobs, reducing emissions, and reducing energy costs to the neediest. The 2007 EISA legislation authorized \$900 million for this purpose. In the longer term, the WAP could be further expanded to allow a rapid retrofit of the remaining 15 million eligible homes that DOE considers cost-effective for weatherization. The current project director has estimated that expanding the program to retrofit one million homes per year would create 78,000 jobs; expansion at that scale, however, would require rapidly training a large number of people and providing weatherization companies and workers some long-term certainty about the scope of the program (Wald 2008).

The WAP has provided weatherization retrofits to 5.6 million low-income families over the past 29 years. DOE estimates that each \$1 invested in the WAP produces \$1.53 in energy-related benefits and \$1.16 in ancillary benefits. DOE analyses suggest that the WAP reduces low-income energy bills by an average of 21 percent, or \$358 per year, based on 2005 spending levels. DOE estimates that every \$1 million invested creates 52 direct jobs and additional jobs for subcontractors and material suppliers (EERE 2008b).

In addition to private-sector buildings and homes, there are a very large number of public-sector buildings in the United States. Retrofitting all public buildings using known energy-efficient technologies—such as high-performance windows; efficient heating, ventilation and air-conditioning systems; high-efficiency lighting; geothermal heating and cooling systems; and more—would create a larger market for energy-saving technologies, reduce public-sector energy bills, and create jobs.

The federal government could start by using state and local government energy-efficiency programs to administer funds. In the longer run, the scope of the program retrofitting all public buildings could be expanded through a federal government-run grant program like the Community Development Block Grants or the authorized, but as of now unfunded, Energy Efficiency and Conservation Block Grants (Pollin et al. 2008).

To retrofit all public buildings would require a substantial investment. According to the most recent Commercial Buildings Energy Consumption Survey, about 20 billion square feet of building stock in the United States was devoted primarily to education, government offices, and hospitals at the end of 2003. According to a study by the U.S. Green Building Council, it would cost \$1.30 per square foot to retrofit these buildings effectively, leading to an estimate of roughly \$26 billion to retrofit all public buildings (Pollin et al. 2008). But this investment would more than pay for itself by reducing the government's long-term energy costs. An investment of this size would also increase the supply and demand for training in energy-efficient building design and construction.

7 MEETING THE ENERGY-INNOVATION CHALLENGE

The energy challenges facing the United States and the world are daunting. To meet them without undue cost and disruption will require major innovations in energy use and supply. But with a comprehensive, integrated energy-innovation strategy; a substantial increase in funding for energy RD&D; new approaches to managing the effort and to cooperating with the private sector and with other countries; and appropriately structured programs to move improved energy technologies from RD&D to widespread deployment, the United States can meet these challenges, reducing emissions while reestablishing its leadership in the growing global markets for innovative energy technologies.

NOMENCLATURE

Acronym	Name
APS	American Physical Society
BES	Basic Energy Sciences
BESAC	Basic Energy Sciences Advisory Committee
BT	Building technologies
CAFE	Corporate Average Fuel Economy
CCS	Carbon capture and storage
CCTP	U.S. Climate Change Technology Program
DOE	Department of Energy
DSM	Demand Side Management
EERE	Office of Energy Efficiency and Renewable Energy at the DOE
EISA	Energy Security and Independence Act of 2007
EFRC	Energy Frontier Research Center
EPAct	Energy Policy Act of 2005
EPRI	Electric Power Research Institute
ERD&D	Energy, Research, Development, and Demonstration
ERD3	Energy, Research, Development, Demonstration, and Deployment
ETI	Energy-Technology Innovation
FERC	Federal Energy Regulatory Commission
FY	Fiscal year
GHG	Greenhouse gas
GNEP	Global Nuclear Energy Partnership
GRI	Gas Research Institute
IGCC	Integrated Gasification Combined Cycle power plant
MIT	Massachusetts Institute of Technology
NCSX	National Compact Stellarator Experiment
OECD	Organization for Economic Cooperation and Development
PCAST	President's Committee of Advisors in Science and Technology
R&E	Research and experimentation
R&D	Research and Development
RPS	Renewable Portfolio Standard
USDA	U.S. Department of Agriculture
USCOC	U.S. Chamber of Commerce
VC	Venture capital
VT	Vehicle technologies
ZEB	Zero Energy Building

REFERENCES

- Anadon, L.D. & Holdren, J.P. 2009, "Policy for Energy-Technology Innovation" in *Acting in Time on Energy Policy*, ed. K.S. Gallagher, Brookings Press (upcoming).
- Anadon, L.D., Gallagher, K.S. & Bunn, M. 2008, "DOE FY09 Budget Request for Energy Research, Development & Demonstration – Commentary", *Energy Technology Innovation Policy research group, Belfer Center for Science and International Affairs*, June.
- APS 2008, "Energy Future. Think Efficiency. How America Can Look Within to Achieve Energy Security and Reduce Global Warming", *American Physical Society*, September.
- APS 2005, "Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk", *Nuclear Energy Study Group, American Physical Society Panel on Public Affairs*, May.
- Apt, J., Lave, L.B. & Pattanariyankool, S. 2008, "A National Renewable Portfolio Standard? Not Practical", *Issues in Science and Technology*, Fall.
- ASERTTI 2008, "Letter with Recommendations for President-elect Obama", *Association of State Energy Research and Technology Transfer Institutions*.
- Atkinson, R.D. 2007, "Expanding the R&E tax credit to drive innovation, competitiveness and prosperity", *Journal of Technology Transfer*, vol. 32, pp. 617-628.
- Bielicki, J.M. 2009, "Deployment Lessons for Burying Climate Change with Carbon Capture and Storage. Chapter 4: Technological Learning and Spillovers in CO₂ Injection", *Unpublished Ph.D. Dissertation. Harvard University. John F. Kennedy School of Government*.
- Bloom, N., Griffith, R. & Van Reenen, J. 2002, "Do R&D tax credits work? Evidence from a panel of countries 1979-1997", *Journal of Public Economics*, vol. 85, pp. 1-31.
- Britt, R. 2008, August 2008-last update, *National Science Foundation. Universities Report Continued Decline in Real Federal S&E Funding in FY 2007*. Available: <http://www.nsf.gov/statistics/infbrief/nsf08320/> [2009, 1/19].
- Bunn, M. 2007, "Risks of GNEP's Focus on Near-Term Reprocessing", *Testimony to the Senate Committee on Energy and Natural Resources*, November 14.
- CA-CP 2008, "Building a Foundation for Success: Recommendations for Early Action on Climate Change for the 44th President of the United States", *Clean Air-Cool Planet*.
- CCS Reg 2009, "Key Points from the CCS Reg Interim Report", *CCS Reg*. January 9.
- CCTP 2006, "CCTP Strategic Plan. Appendix A", *U.S. Climate Change Technology Program*.
- Chuang, A. 2008, "EPRI Smart Grid R&D Overview", *EPRI. Presentation at HP Sustainability Innovation Workshop*, [Online], October 20.
- DOE 2007a, "The Smart Grid: An Introduction", *U.S. Department of Energy. By Litos Strategic Communication*, September.
- DOE 2007b, "A Vision for the Modern Grid", *U.S. Department of Energy. National Energy Technology Laboratory*, March.
- DOE 2006, "Fact Sheet. U.S. Department of Energy Cooperation with the People's Republic of China", *U.S. Department of Energy*, April.
- DOT 2008, "Notice Requesting Expressions of Interest in Implementing a High-Speed Intercity Passenger Rail Corridor", *Federal Register. Notices* December 16, vol. 73, no. 242, pp. 76443.
- EERE 2008a, "20% Wind Energy by 2030", *U.S. Department of Energy. Office of Energy Efficiency and*

Renewable Energy, vol. May.

- EERE 2008b, "2008 Weatherization Assistance Program Briefing Book", U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy, August.
- EERE 2008c, "An Evaluation of Enhanced Geothermal Systems Technology. Geothermal Technologies Program", U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy.
- EIA 2008, "Federal Financial Interventions and Subsidies in Energy Markets 2007", Energy Information Administration. Office of Coal, Nuclear, Electric, and Alternate Fuels.
- EU MEMO/08/796 2008, *Questions and Answers on the revised EU Emissions Trading System*. Question 7.
- Gallagher, K.S. 2009, "Acting in Time on Climate Policy" in *Acting in Time on Energy Policy* Brookings Press (upcoming).
- Gallagher, K.S. & Collantes, G. 2008, "Analysis of Policies to Reduce Oil Consumption and Greenhouse Gas Emissions from the U.S. Transportation Sector", *ETIP Discussion Paper 2008-06*, June.
- Gallagher, K.S. & Holdren, J.P. 2004, "U.S. Government Policies Relating to International Cooperation on Energy", *National Commission on Energy Policy Report*.
- Gallagher, K.S., Holdren, J.P. & Sagar, A.D. 2006, "Energy-Technology Innovation", *Annual Review of Environmental Resources*, vol. 31, pp. 193-237.
- Gallagher, K.S. 2008, "DOE Budget Authority for Energy Research, Development, and Demonstration Database", *Energy Technology Innovation Policy Group*. Harvard Kennedy School of Government. June.
- Grübler, Arnulf (convening lead author) 2009, "The Energy Innovation System. Knowledge Module 24", *Global Energy Assessment*.
- Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., Pagani, M., Raymo, M., Royer, D.L. & Zachos, J.C. 2008, "Target Atmospheric CO₂: Where Should Humanity Aim?", *The Open Atmospheric Science Journal*, vol. 2, pp. 217-231.
- Hendricks, B. & Goldstein, B. 2008, "A Strategy for Green Recovery: Stimulating the Economy Today by Building Future Prosperity", *Center for American Progress Action Fund*, November.
- Kuuskraa, V.A. 2007, "A Program to Accelerate the Deployment of CO₂ Capture and Storage (CCS): Rationale, Objectives, and Costs", *Pew Center on Global Climate Change. Coal Initiative. White Paper Series*.
- Lee, Henry. 2009, "Oil Security and the Transportation Sector" in *Acting in Time on Energy Policy*, ed. K.S. Gallagher, Brookings Press (upcoming).
- Metcalf, G. 2007, "A Proposal for a U.S. Carbon Tax Swap: An Equitable Tax Reform to Address Global Climate Change", *Discussion Paper 2007-12. Hamilton Project. Brookings Institution*, November.
- MIT 2006, "The Future of Geothermal Energy. Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century", *Massachusetts Institute of Technology*.
- MIT 2003, "The Future of Nuclear Power. An Interdisciplinary MIT study", *Massachusetts Institute of Technology*, pp. 75.
- NAS 2005, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Washington D.C.
- NCEP 2004, "Ending the Energy Statemate. A Bipartisan Strategy to Meet America's Energy Challenges", *The National Commission on Energy Policy* pp. 99.

- NEF 2008, "New Energy Finance Desktop 3.0", *New Energy Finance*.
- NRC 2007, "Review of DOE's Nuclear Energy Research and Development Program", Committee on Review of DOE's Nuclear Energy Research and Development Program. National Research Council, [Online].
- Obama, B. 2008, "President-elect Obama promises 'new chapter' on climate change. Global Climate Summit", *The Office of the President-elect*.
- Ogden, P., Podesta, J. & Deutch, J. 2008, "A New Strategy to Spur Energy Innovation", *Issues in Science and Technology*, Winter.
- PCAST 1999, "Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation", *President's Committee of Advisors on Science and Technology*.
- PCAST 1997, "Federal Energy Research and Development for the Challenges of the Twenty-First Century", *President's Committee of Advisors on Science and Technology*, Chapter 1, Washington D.C.
- Peña, N. & Rubin, E.S. 2008, "A Trust Fund Approach to Accelerating Deployment of CCS: Options and Considerations", *Pew Center on Global Climate Change. Coal Initiative. White Paper Series*.
- Pollin, R. 2008, "Hearing on 'The Green Road to Economic Recovery'", *Testimony before the House Select Committee on Energy Independence and Global Warming*, September 18, pp. 7-8.
- Pollin, R., Garrett-Peltier, H., Heintz, J. & Scharber, H. 2008, "Green Recovery. A Program to Create Good Jobs and Start Building a Low-Carbon Economy", *Center for American Progress and Political Economy Institute*, September.
- RAND 2008, *Major Progress in Technology Needed for 25 Percent Renewable Energy Use to be Affordable*.
- Rubin, E.S. 2008, "Testimony of Edward S. Rubin to the Subcommittee on Energy and Air Quality Committee on Energy and Commerce U.S. House of Representatives", *Testimony before the Subcommittee on Energy and Air Quality Committee on Energy and Commerce. U.S. House of Representatives*.
- Schrag, D. 2009, "Making Carbon Capture and Storage Work" in *Acting in Time on Energy Policy*, ed. K.S. Gallagher, Brookings Press (upcoming).
- Terry, D. 2009, *Executive Director of ASERTTI. Conversation about ASERTTI's recommendations to President Obama*. January 23.
- USCOC 2003, "Chamber supports H.R. 463 and S. 664, the R&E Credit", *U.S. Chamber of Commerce. 2003 Letters to Congress*.
- Wald, M.L. 2008, "Focus on Weatherization Is Shift on Energy Costs." *The New York Times*. December 30.
- Warda, J. 2006, "Tax treatment of investment in intellectual assets: An international comparison", *OECD Science Technology and Industry Working Papers*, April.
- Wiser, R. & Barbose, G. 2008, "Renewable Portfolio Standards in the United States. A Status Report with Data Through 2007", *Lawrence Berkeley National Laboratory*, April.
- Woolsey, J.R. & Korin, A. 2008, "How to Break Both Oil's Monopoly and OPEC's Cartel", *Innovations*, vol. 3, no. 4, pp. 35-38.

ABOUT THE ENERGY TECHNOLOGY INNOVATION POLICY GROUP

The overarching objective of the Energy Technology Innovation Policy (ETIP) research group is to determine and then seek to promote adoption of effective strategies for developing and deploying cleaner and more efficient energy technologies, primarily in three of the biggest energy-consuming nations in the world: the United States, China, and India. These three countries have enormous influence on local, regional, and global environmental conditions through their energy production and consumption.

The ERD3 Project is a three-year effort within ETIP funded by the Doris Duke Charitable Foundation aimed at producing a set of comprehensive recommendations for the next U.S. administration to accelerate energy-technology innovation (ETI). ERD3 Project members are working in three main areas: (a) identifying the opportunities for government-funded energy research, development and demonstration (ERD&D), and developing a portfolio of U.S. government investments in ERD&D and the components of a coordinated ETI strategy; (b) understanding the private sector's current role in carrying out and funding of ERD&D in United States and drawing conclusions about effective structures of public-private undertakings and other incentives to promote private sector innovation; and (c) analyzing the global picture of energy-technology innovation to make recommendations on a strategy and priorities for international cooperation on ETI for the United States.

ERD3 Project Members and Contributors

Laura Diaz Anadon, Project Manager

Kelly Sims Gallagher, Director of Energy Technology Innovation Policy research group

Matthew Bunn, Associate Professor of Public Policy

John P. Holdren, Teresa and John Heinz Professor of Environmental Policy (until 20 January 2009)

Melissa Chan, Research Fellow (starting in January 2009)

Jose Condor, Research Fellow

Charles Jones, Research Fellow

Stephen Elliott, Research Assistant

Please visit us at www.energytechnologypolicy.org or contact us by e-mail at etip@ksg.harvard.edu.

Energy Technology Innovation Policy
Belfer Center for Science and International Affairs
Harvard Kennedy School of Government
Harvard University
79 John F. Kennedy Street, Mailbox 53
Cambridge, MA 02138